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GCA Corp, Bedford, MA GCA Technology Div

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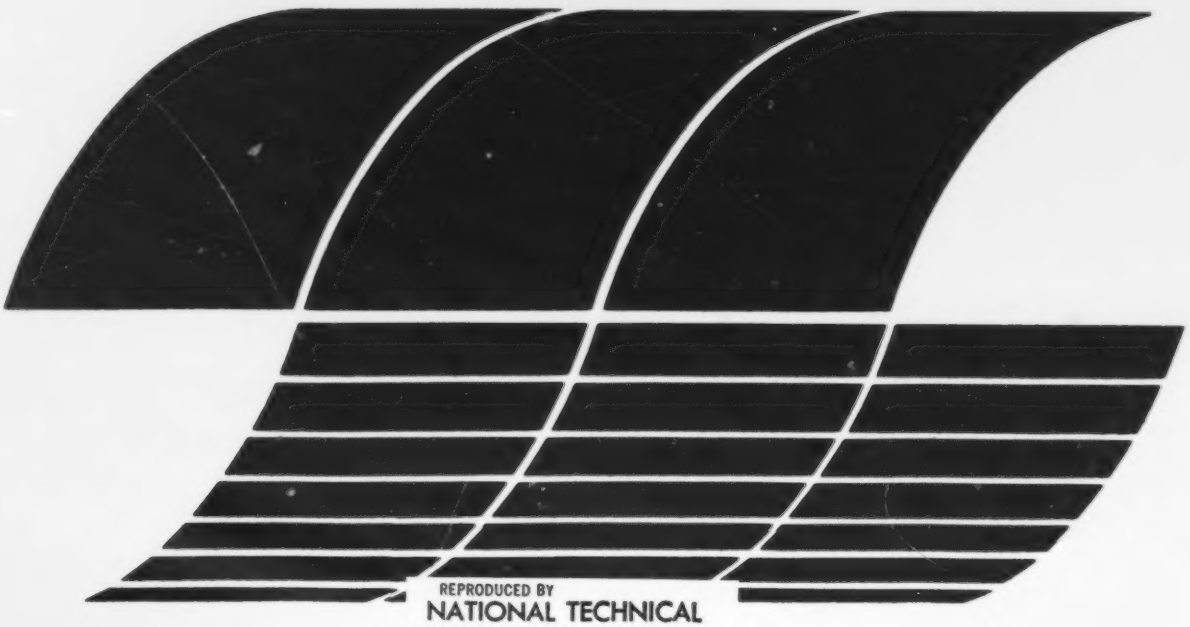

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Mathematical Models	Aerosols	Stationary Sources	12A	
Filtration	Dust	Fabric Filters	07D	11G
Fly Ash	Utilities	Particulate	21B	
Coal	Boilers		21D	13A
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ABSTRACT

A new mathematical model is described for use by control personnel to determine the adequacy of existing or proposed filter systems designed to minimize coal fly ash emissions. Although the basic model design is similar to that discussed in an earlier report, several improvements and many timesaving steps have been introduced so that the immediate needs of agency and other emissions control enforcement groups can be met. To further aid the model user, the study has been presented in two volumes, the first a Detailed Technical Report and the second a User's Guide.

The model is structured so that by using the combustion, operating, and design parameters indicated by power plant and/or manufacturing personnel, the program user can forecast the expected particulate emissions and filter pressure loss.

The program affords the option of providing readily appraised summary performance statistics or highly detailed results if the latter are necessary. Several built in error checks prevent the generation of useless data and avoid unnecessary computer time.

The model takes into account the concentration and specific resistance properties of the dust, air/cloth ratio, sequential compartmentized operation and the method, intensity and frequency of cleaning. The model function depends upon the unique fabric cleaning and dust penetration properties observed with several coal fly ashes (including lignite) and woven glass fabrics. Prior validation of a precursor model showed excellent agreement with measured field performance for the Sunbury, Pennsylvania and Nucla, Colorado fabric filter systems.

CONTENTS

Abstract iii
List of Figures vi
List of Tables vi
Acknowledgments vii

1.0 Introduction 1
1.1 Background 1
1.2 Role of User's Guide 1
1.3 Input Variables 2
2.0 Data Input Forms 5
2.1 Card 1 - Heading or Title Card 5
2.2 Card 2 - Design Data 5
2.3 Card 3 - Operating Data 7
2.4 Card 4 - Specific Resistance Coefficient (K_2)/Gas and Dust Properties 7
2.5 Card 5 - Fabric and Gas Properties 8
2.6 Card 6 - Special Program Instructions 9
2.7 Card 7 - Plot (Graph) Dimensions 10
3.0 Error Messages 11
4.0 Example of Model Application 14

References 22

FIGURES

Number		Page
1	Fabric filter model - data input form	4
2	Fabric filter model - data input form prepared from Table 3 input data	18

TABLES

1	Summary Listing of Input Data for Filtration Model	3
2	Summary of Diagnostic Messages and Their Interpretation	12
3	Available Input Data for Modeling Baghouse Performance at Electric Utility, Plant B	15
4	English/Metric Conversion Factors	16
5	Samples of Tabular Printout for Example of Model Application . .	20

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1.0 INTRODUCTION

1.1 BACKGROUND

A comprehensive treatment of the development and design of a new fabric filtration model, structured specifically so that enforcement engineers can assess the fly ash control capabilities of filter systems used at coal burning facilities, is presented in Volume I of this report. Several open literature publications are also available including reports of studies sponsored by the U.S. Environmental Protection Agency that provide further insight into the historical and technical aspects of the model development.[1-6]

1.2 ROLE OF USER'S GUIDE

The brief description of the filter model application presented in this volume serves as a convenient field instruction guide for agency and other personnel who possess a rudimentary knowledge of filtration technology and computer methodology. It is intended that the model will enable field engineers to determine whether a proposed or existing fabric filter system will, or should be able to, reduce fly ash emissions to required levels.

By following the instructions set forth in this guide, the model user can collect and organize the required information for correct entry on specially prepared data input forms. From this point on, use of conventional punch-carding and programming routines will provide enforcement personnel with a tabular printout of predicted filter system performance at whatever degree of detail and accuracy is needed for a specific filter system evaluation.

The following information is provided in this document:

- A description of each input variable.
- Error messages, probable cause and correction.
- An example of model application.

1.3 INPUT VARIABLES

For immediate reference, a listing of the input variables used with the filtration model is presented in Table 1. Data inputs are grouped in four categories: Design Data, Operating Data, Dust and Fabric Properties and Special Program Instructions. Table 1 also shows the correct units for each data input as well as the Card and Item number for entry on the Data Input Form, Figure 1. Additionally, the valid ranges, i.e., the range of numerical values that will allow the program to run, are indicated for key variables. Table 1 also indicates Default Values which are automatically assigned by the program when no data inputs are available or when the model user forgets to make an entry.

TABLE 1. SUMMARY LISTING OF INPUT DATA FOR FILTRATION MODEL

		Item	Symbol	Units	Card	Valid range	Default*	Note
	0	Title		-	1			
DESIGN DATA	1	Number of compartments	n	-	2	2 to 30		
	2	Compartment cleaning time	Δt	min	2	0.5(Item 3/Item 1)		
	3	Cleaning cycle time	Σt	min	2			
	4	Time between cleaning cycles	t_f	min	2			a
	5	Limiting pressure drop	P_L	N/m^2	2			a
	6	Reverse flow velocity	V_R	m/min	2		0	b
	7	Shaking frequency	f	cps	2			b
	8	Shaking amplitude (half stroke)	A	cm	2			b
OPERATING DATA	9	Average face velocity	V	m/min	3	0.3 to 3.0		
	10	Gas temperature	T	^oC	3	>0		
	11	Inlet dust concentration	C_i	g/m^3	3			
	12	measured at temperature of	T	^oC	3		25	
DUST AND FABRIC PROPERTIES	13	Specific resistance coefficient	K_2	N-min/g-m	4	0.25 to 10		c,d
	14	measured at temperature of	T	^oC	4	>0	25	
	15	measured at velocity of	V	m/min	4		0.61	
	16	measured at mass median diameter of	MMD_1	μm	4	2 to 50		d
	17	measured at geometric standard deviation of	σ_{g1}	-	4 4	2 to 4		d
	18	Mass median diameter of inlet dust	MMD_2	μm	4	2 to 50		d,e
	19	Geometric standard deviation of inlet dust	σ_{g2}	-	4	2 to 4		d,e
	20	Discrete particle density of inlet dust	ρ_p	g/cm^3	4			e
	21	Bulk density of inlet dust	$\bar{\rho}$	g/cm^3	4			e
	22	Effective residual drag	S_E	$N-min/m^3$	5		350†	f,g
	23	measured at temperature of	T	^oC	5	>0	25	
	24	Residual fabric loading	W_R	g/m^2	5		50†	f,g
	25	Residual drag	S_R	$N-min/m^3$	5			f
	26	measured at temperature of	T	^oC	5	>0	25	
	27	Initial slope	K_R	N-min/g-m	5			f
	28	measured at temperature of	T	^oC	5	>0	25	
SPECIAL PROGRAM INSTRUCTIONS	29	Maximum number of cycles modeled	nc	-	6			h
	30	Accuracy code	0 or 1	-	6	0 or 1	0	
	31	Type of tabular results	-	-	6		Average	i
	32	Type of plotted results	-	-	6			i
	33	Fractional area cleaned	a_c	-	6	>0 to 1		j
	34	x axis length		inches	7		6	k
	35	y axis length		inches	7		5	

*These values are used when no entry has been made for the parameter.

†Default values assigned only when no data inputs are available for S_E, W_R and K_2.

Notes:
a. Enter item 4 or 5, but not both.
b. Enter item 6 or (7 and 8), but not both.
c. Enter items 13 through 15 when K_2 measurement is available.
d. Enter items 13 through 19 when K_2 measurement must be corrected for size properties.
e. Enter items 18 through 21 when K_2 is to be estimated from dust size and density parameters.
f. Enter items 22 through 28 for nonlinear drag model.
g. Enter items 22 through 24 for linear drag model.
h. Generally 20 cycles are sufficient.
i. For tabular results specify DETAILED, SUMMARY or AVERAGE; for graphical results specify PLOT or leave blank.
j. Enter only in special case when a_c measurement is available.
k. Card can be left out if default values are sufficient or if no plotted output is desired.

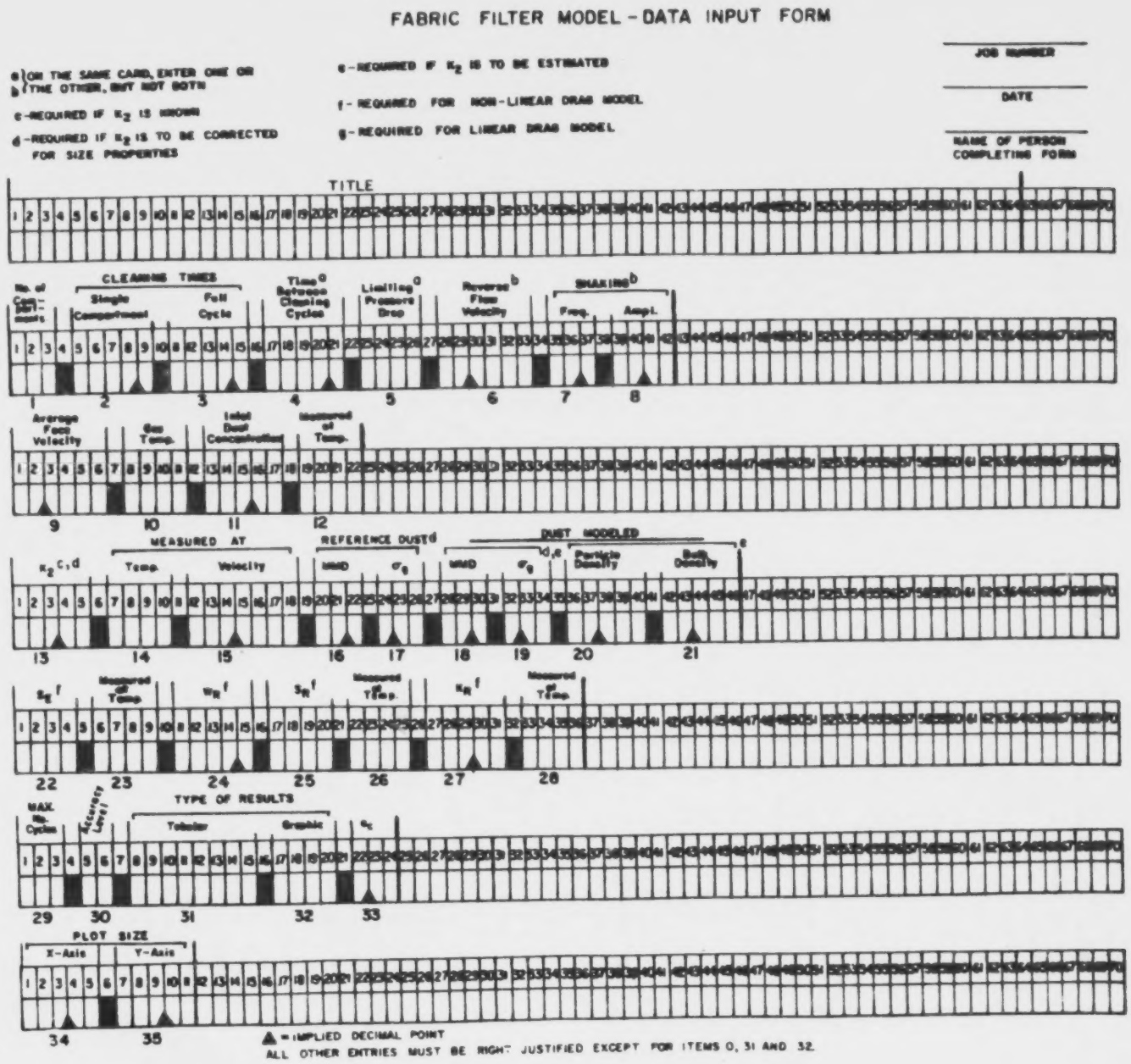

Figure 1. Fabric filter model - data input form.

2.0 DATA INPUT FORMS

Card identification, the type of information entered on each card, instructions relating to unusual or mutually exclusive entries, and acceptable numerical ranges for specific variables, are discussed in this section.

2.1 CARD 1 - HEADING OR TITLE CARD

A descriptive title identifying the specific modeling run is entered in up to 64 characters on Card 1.

2.2 CARD 2 - DESIGN DATA

The number of compartments (Item 1) is the total number of compartments (or chambers) in the baghouse, from 2 to 30. If the compartments are cleaned one at a time on a sequential basis, the actual number of compartments must be entered. If more than one compartment is cleaned simultaneously, the revised or effective value for number of compartments is the total number divided by the number undergoing simultaneous cleaning. Note that entry spaces with no triangular decimal point indicator require right justification for whole number inputs such as Item 1. Otherwise, the presence of the triangle specifies the decimal point location, Item 2.

The compartment cleaning time (Item 2) is the length of time that a single compartment remains out of service during its cleaning. Although the program will operate if Item 2 is left blank, it is recommended that the actual value be entered when available. If left blank, a default value equal to one-half of the quotient of the full cycle cleaning time divided by the number of compartments is automatically calculated by the program.

The cleaning cycle time (Item 3) is the length of time required to complete an entire cleaning cycle; i.e., the time required to clean all baghouse compartments. A value for the cleaning cycle time must be entered for the program to function.

The method by which the cleaning cycle is regulated is identified by Item 4 or 5. For those systems where continuous cleaning has been specified the baghouse cleans continuously (back-to-back cleaning cycles). With no time between cleaning, both Items 4 and 5 must be left or given zero entries. On the other hand, if the system is required to filter without cleaning for a specific time interval following each cleaning cycle, then the time between cleaning cycles must be entered in Item 4 (with no entry for Item 5). Conversely, if the system is expected to filter after the cleaning cycle until a specified limiting pressure drop is reached, then the limiting pressure drop must be entered in Item 5 (with no entry for Item 4). Note that although a limiting pressure drop system may also function with a finite time between cleaning cycles, the latter value is not known at the inception of the modeling. In the above case, the time between cleaning is calculated from the computer printout of model results.

Items 6 through 8 describe the fabric cleaning parameters. If reverse flow cleaning (with bag collapse) is the sole cleaning method, the reverse flow velocity only (Item 6) is entered. Conversely, if mechanical shaking with no reverse flow is used, both shaking frequency and amplitude (Items 7 and 8) must be entered. For most combustion processes where the reverse flow cleaning action is the predominant cleaning mechanism, the actual reverse flow velocity alone is entered. If no entry is made for reverse flow velocity

or its value cannot be determined, the model will automatically assign a default value of zero so that the program will continue to operate.

2.3 CARD 3 - OPERATING DATA

The average face velocity (Item 9 air-to-cloth ratio) must always be entered and at the actual filtration temperature (Item 10). The average face velocity is computed from the total volume flow through the baghouse and the total effective filtration area. The actual gas temperature (Item 10) and the inlet dust concentration (Item 11) are also prerequisite entries. If the inlet concentration is reported at a temperature other than 25°C, the temperature must be entered in Item 12.

2.4 CARD 4 - SPECIFIC RESISTANCE COEFFICIENT (K_2)/GAS AND DUST PROPERTIES

The specific resistance coefficient, K_2, and/or associated dust properties are entered via Card 4. When the K_2 value for the dust being filtered is known, K_2 (Item 13) and the temperature and face velocity at which K_2 was determined (Items 14 and 15) must be entered. If no entries are made for Items 14 and 15, the program automatically assigns default values of 25°C and 0.61 m/min, respectively. If a measured K_2 value for the same dust but for a different size distribution is available, then Items 13 through 19 must be entered. The program will then compute the correct K_2 value for the dust to be filtered based upon the adjustment for size properties. If no measured K_2 is available, then the size (actual) and density parameters of the filtered dust (Items 18 to 21) must be entered.

The program will operate correctly with respect to Items 13 through 21 for the following data input combinations:

- Item 13 alone
- Items 13 through 15 alone

- Items 13 through 19 alone
- Items 13, 16 through 19
- Items 18 through 21 alone

Any other combinations will generate an error message. If the model user forgets to enter any values for Items 14 and 15, the program automatically assigns default values of 25°C and 0.61 m/min as stated previously. Inspection of the summary data input printout will indicate the error to the model user if the true values differ from the input or default values.

2.5 CARD 5 - FABRIC AND GAS PROPERTIES

Additional parameters used to establish the drag versus fabric loading relationship for the dust/fabric combination of interest are indicated on Card 5. When all terms described on Card 5 are known prior to the modeling effort (Items 22 through 28), their entry will automatically lead to the programs selection of the nonlinear drag model (which provides the more rigorous definition of the drag-fabric loading relationship). If the reference measurement temperature for S_E, W_R, S_V and K_R is not entered, the program will automatically assign a default value of 25°C. If the latter value is not correct, the model user will detect the temperature error when scanning the tabular summary data printout. If the linear drag model is to be used, it is only necessary to enter S_E and W_R when available (Items 22 and 24) and the corresponding measurement temperature if not equal to 25°C. Finally, when no input data are available for Items 22 through 28, which means that K_2 must be estimated by the program (Card 4, Items 18 through 21), all Card 5 entries may be left blank. Items 22 and 24, S_E and W_R, respectively, will automatically be assigned default values for 25°C, thus permitting the program to proceed with the linear modeling approach.

2.6 CARD 6 - SPECIAL PROGRAM INSTRUCTIONS

The terms appearing on Card 6 relate to the level of accuracy desired and the amount of detail to be presented to the model user in the model printout. When a specific numerical value is entered for the maximum number of cycles, Item 29, the program will automatically continue cycling until convergence is achieved or until the specified number of cycles have been modeled. However, printout data will be provided for the last 3 cycles only, thus eliminating excess and ordinarily useless printout material. A cycle refers to the time period embracing both the cleaning and filtration intervals.

In most cases, near steady state filtration conditions will be established within 20 cycles. If no entry is made for Item 29, the program will automatically stop after 4 cycles regardless of whether convergence (steady state) is indicated by the tabular printout for the AVERAGE values for the last 3 cycles. Concurrently, a nonconvergence message is indicated so that the model user can run additional cycles if desired.

Regardless of the number of cycles requested, the model is structured so that the program will execute only as many cycles as necessary to achieve convergence (steady state) by means of a convergence checking system within the program. This step can result in a significant reduction of computer time.

An entry of zero for the accuracy level, Item 30, instructs the program to define the convergence limits (approach to steady state) within 1 percent of the estimated limiting value. Should the model user desire a closer approximation, the assignment of the integer value of 1 will reduce the above differential to about 0.3 percent. However, except for unique circumstances, the added accuracy constraint may not be justifiable since both computer time and costs will be roughly doubled.

Items 31 and 32 enable the selection of the type and extent of program printout necessary for the specific modeling application. If DETAILED is requested for the tabular printout, the local drag and velocity for each fabric element (area) of the system as well as drag, velocity and loading for each compartment for each time iteration (increment) will be printed. In addition, a summary table of total system penetration and average pressure drop plus individual compartment flow velocities will be printed. Finally, the average and maximum pressure drop and penetration will be printed for the final 3 cycles depicting steady state operation.

When SUMMARY is specified, the summary table cited above but without compartment flow velocities, will be printed along with the cycle average and maximum values for pressure drop and penetration. A request for AVERAGE data provides the average statistics only for a complete operating cycle. For most field diagnostic applications of the model, the AVERAGE printout category should suffice. Should time plots be desired for pressure loss and penetration behavior, PLOT is entered in Item 32.

If the fractional area cleaned, a_c, is known, it can be entered via Item 33. Since in most instances no value of a_c will be available, Item 33 will be left blank.

2.7 CARD 7 - PLOT (GRAPH) DIMENSIONS

If plots of a size other than those specified as default values are desired, the plot dimensions (Items 34 and 35) must be entered.

3.0 ERROR MESSAGES

Table 2 summarizes the various error messages that can result when certain data are omitted, entered incorrectly, or do not fall in the valid range. The program will not operate until these errors are corrected. The error messages will appear on a separate printout sheet captioned DIAGNOSTIC MESSAGES.

TABLE 2. SUMMARY OF DIAGNOSTIC MESSAGES AND THEIR INTERPRETATION

Message*	Probable cause/corrective measures
- ILLEGAL REQUEST FOR TYPE OF RESULTS	Incorrect spelling of DETAILED, SUMMARY, AVERAGE or PLOT for Items 31 and 32, Card 6.
- THE NUMBER OF COMPARTMENTS MUST NOT EXCEED 30	Too many compartments were entered for Item 1, Card 2.
- THE NUMBER OF COMPARTMENTS TIMES THE COMPARTMENT CLEANING TIME MUST BE LESS THAN THE CLEANING CYCLE TIME	Too many compartments, too large a compartment cleaning time or too small a cleaning cycle time were specified - Items 1, 2, and 3, Card 2.
- THE COMPARTMENT CLEANING TIME MUST BE LESS THAN THE TOTAL CYCLE TIME	Too large a compartment cleaning time, Item 2, Card 2, or too small a cleaning cycle time, Item 3, Card 2, were specified.
- TIME INCREMENT TOO SMALL, I.E., < 0.01 MINUTES	The time increment calculated by the program is too small. Too many compartments (Item 1, Card 2) or too small a cleaning cycle time, Item 3, Card 2, will cause this problem.
- AVERAGE FACE VELOCITY OUT OF RANGE, 0.3 TO 3.0	Too large or too small an average face velocity was entered for Item 9, Card 3.
- A GAS TEMPERATURE HAS NOT BEEN ENTERED	A value less than or equal to $0^{o}C$ was entered for Item 10, Card 3.
- INVALID FREQUENCY OR AMPLITUDE FOR SHAKER	A > 0 value entered for either frequency, Item 7, Card 2 or amplitude, Item 8, Card 2. Both must be entered or left blank for program to operate.
- INVALID ACCURACY CODE	Only Ø and 1 are valid codes. Make certain the number is right justified when entered for Item 30, Card 6.
- BOTH TIMED AND PRESSURE CONTROLLED CLEANING SPECIFIED - ONLY ONE IS VALID	On Card 2, values for both Items 4 and 5 were entered. Only one item may be entered per test.
- PARTICLE SIZE DATA FOR K_2 ARE INCOMPLETE	A value for K_2, Item 13, Card 4, was entered along with data to be used in correcting K_2 for dust size properties, Items 16 through 19, Card 4. However, an omission from Items 16 through 19 has led to any of the following error messages.
- MASS MEDIAN DIAMETER OF MEASUREMENT OUT OF RANGE 2 TO 50	The MMD of the reference dust, Item 16, Card 4, is out of the valid range.
- STANDARD DEVIATION OF MEASUREMENT OUT OF RANGE 2 TO 4	The σ_g of the reference dust, Item 17, Card 4, is out of the valid range.
- MASS MEDIAN DIAMETER OF DUST OUT OF RANGE 2 TO 50	The MMD of the inlet dust, Item 18, Card 4, is out of the valid range.

(continued)

TABLE 2 (continued)

Message*	Probable cause/corrective measures
- STANDARD DEVIATION OF DUST OUT OF RANGE 2 TO 4	The σ_g of the inlet dust, Item 19, Card 4, is out of the valid range.
- BULK DENSITY CANNOT EXCEED DISCRETE PARTICLE DENSITY	Too large a bulk density, Items 21, Card 4, or too low a discrete density, Item 20, Card 4, were specified.
- BULK OR DISCRETE DENSITY MISSING	K_2 is to be estimated as is required when no values are entered for K_2 and the reference dust, but either the bulk or discrete particle densities, Items 20 and 21, Card 4, are missing.
- EFFECTIVE DRAG, S_E, IS LESS THAN THE RESIDUAL, S_R	Values for both K_R and S_R, Items 27 and 25, Card 5, were entered, but the values of S_E, Item 22, Card 5, and S_R are inconsistent with theory for the form of of the nonlinear drag curve.
- INCOMPLETE DATA FOR NONLINEAR DRAG MODEL	Only K_R, Item 27, Card 5, or S_R, Item 25, Card 5, was specified. Both terms or neither one should be specified for model to operate.
- RESIDUAL DRAG, S_R, IS MISSING	K_R was entered but S_R was omitted.
- INITIAL SLOPE, K_R, IS MISSING	S_R was entered but K_R was omitted.
- FRACTIONAL AREA CLEANED OUT OF RANGE, > 0 TO 1	The value for a_c entered as Item 33, Card 6, is not in the valid range.
- K_2 IS OUT OF RANGE, 0.25 TO 10	The value of K_2, whether entered or calculated by the program, when corrected to 25°C and 0.61 m/min is not within the valid range. Check data on Card 4 for accuracy.
- THE PROGRAM HAS BEEN TERMINATED BECAUSE OF ERRORS IN THE INPUT DATA	Since one or more of the above errors has occurred, program execution is stopped. Correct the error(s) and rerun the program.
- THERE ARE NO ERRORS IN THE INPUT DATA	No errors were detected. The simulation will be performed.

*Out of order and missing cards (with the exception of Card 7) will cause many of the above errors to occur. Check card order before running program.

4.0 EXAMPLE OF MODEL APPLICATION

An electric utility operates two, coal-burning steam-electric plants, the first of which now uses a pressure-controlled baghouse to prevent particulate (fly ash) emissions. It has been proposed that a continuously cleaned fabric filter system be installed at the second plant. Both the utility operator and the local emission enforcement groups would like to determine whether operation of the filter system in accordance with the input data shown in Table 3 will satisfy local emission requirements while maintaining average system pressure drop levels within the exhaust capacity range of the induced draft fans. For present purposes, it is assumed that operation at an efficiency of 99.5 percent (equivalent to 0.5 percent penetration) and an average pressure drop of < 1750 N/m^2 (7 in. water) indicates acceptable performance.*

Design and operating data appearing in Table 3 for the proposed "second" plant baghouse represent a composite of information received from both utility personnel and the dust collector manufacturer. It is also assumed that previous measurements of uncontrolled mass emission rates and fly ash size distrubutions at both plants are available as well as estimates for the terms K_2, S_E and W_R based upon special tests performed at the first plant. It should be noted that the above terms might have been estimated from strip chart records from

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*Although a lower operating pressure loss is usually preferred, limited physical space and a desire to make use of the existing draft fans has led to the utilities choice of the indicated pressure drop characteristics (< 1750 N/m^2).

TABLE 3. AVAILABLE INPUT DATA FOR MODELING BAGHOUSE PERFORMANCE AT ELECTRIC UTILITY, PLANT B

	Plant A	Plant B
Number of compartments		30
Cleaning cycle duration		30 minutes
Time to clean one compartment		1 minute
Cleaning type		Collapse/reverse air
Reverse flow volume		30,000 acfm
Cleaning cycle initiation		Continuous cleaning
Volume flow into baghouse		600,000 acfm
Total filtration area		200,000 ft^2
Temperature of flue gas		350°F
Inlet concentration		5 grains/scf
Inlet dust mass median diameter	10 μm (Reference)	7 μm
Inlet dust geometric standard deviation	3.0 (Reference)	2.5
Dust specific resistance, K_2	10.2 in.W.C.-ft-min/lb	
Measured at	500°F	
Measured at	2 ft/min	
Effective residual drag	0.636 in.W.C.-min/ft	
Measured at	500°F	
Residual fabric loading	0.015 lb/ft^2	

Note: All English units must be converted to their metric equivalents. See Table 4.

TABLE 4. ENGLISH/METRIC CONVERSION FACTORS

Quantity	To convert from	To	Multiply by
Filter resistance	in. H_2O	N/m^2	249
Filter drag	in. H_2O-min/ft	$N\text{-}min/m^3$	817
Velocity	ft/min	m/min	0.305
Volume flow	ft^3/min	m^3/min	0.0283
Fabric area	ft^2	m^2	0.093
Areal density	lb/ft^2	g/m^2	4882
Specific resistance coefficient	in.W.C.-min-ft/lb	N-min/g-m	0.167
Dust concentration	$grains/ft^3$	g/m^3	2.29
Density	lb/ft^3	g/cm^3	0.0160

the first plant showing the pressure loss versus time traces. There is the important constraint, however, that the time intervals between cleaning be long enough (∿2 hours) to develop a uniform density dust deposit on the fabric surface.

The data summarized in Table 3 are sufficient to carry out the predictive modeling operation. Following transcription of the information from Table 3 into the units and format shown in Figure 2, the data inputs are ready for punch-carding.

Card 1 contains the title which will appear with the results. Note that on Card 2 the time between cleaning cycles, Item 4, and the limiting pressure, Item 5, have been left blank because a continuous cleaning system has been chosen. The reverse flow velocity, Item 6, Card 2, is calculated from the total reverse flow rate (30,000 acfm) and the cloth area per compartment (200,000 ft^2/30) as 4.5 ft/min or 1.37 m/min. The average face velocity, Item 9, Card 3, is computed from the indicated value for the total gas flow (600,000 acfm) and the total fabric area (200,000 ft^2) as 3.0 ft/min (0.915) m/min). Inlet concentration is reported at ambient temperature, ∿25°C, the value entered for Item 12, Card 3.

The data available for K_2 are sufficient to allow for correction of the measured K_2 at the first plant to the size properties of the dust at the second plant. Thus K_2, the temperature and face velocity at which it was measured and the size properties of the two dusts are entered as shown on Card 4. The model user should note that much of the raw field data may appear in English units, necessitating their conversion to the metric units used in the model.

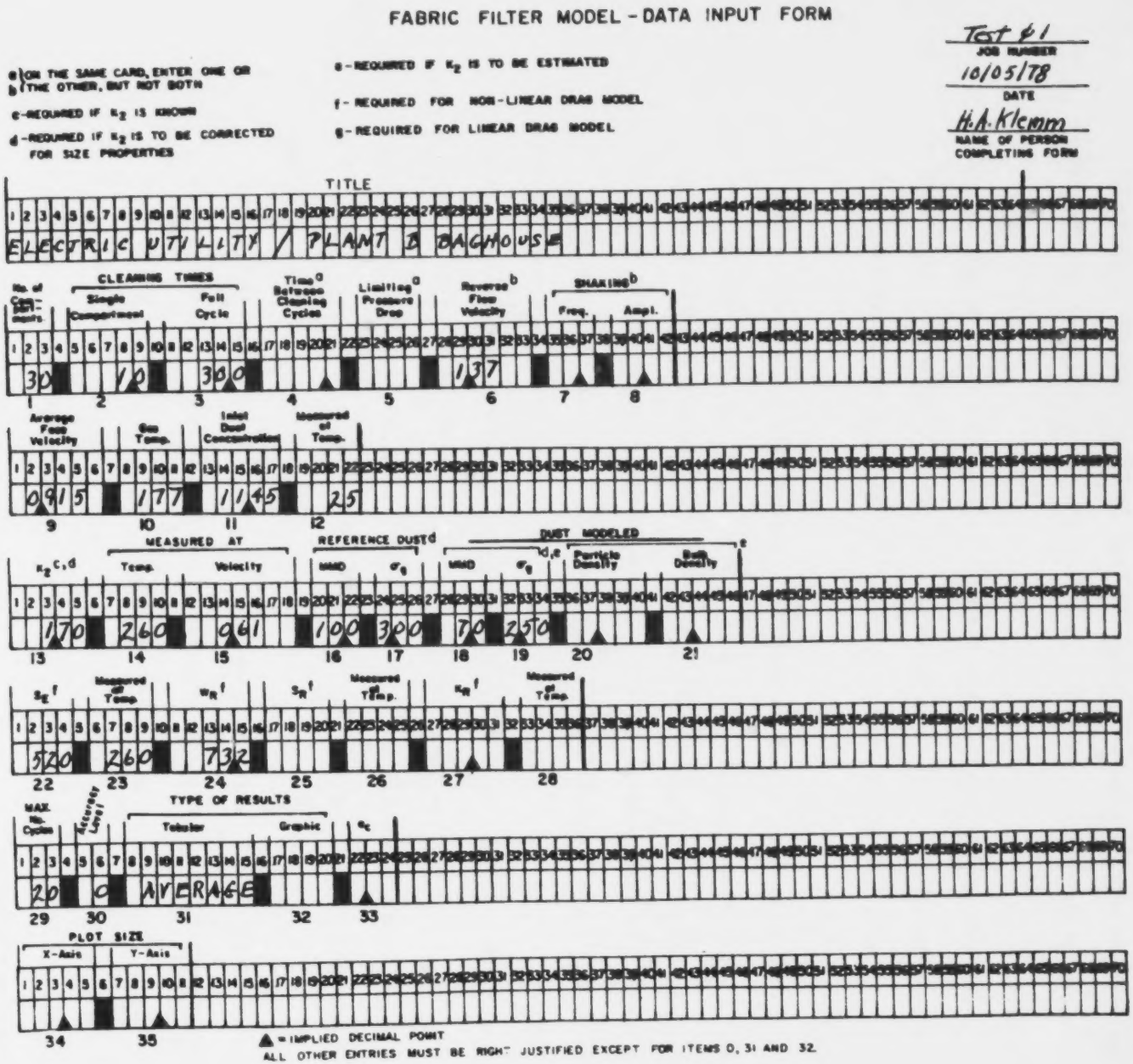

Figure 2. Fabric filter model - data input form prepared from Table 3 input data.

Twenty cycles are considered sufficient to complete the simulation and achieve steady state conditions (see Card 6). Similarly, an accuracy level of zero is considered acceptable for the first trial. Because the utility personnel and the enforcement agency are concerned mainly with average emission rates and average pressure drop, AVERAGE results are requested. Since no plotting is desired, Item 32, Card 7 has been left blank.

If the results of the simulation had indicated emission levels close to, but greater than, the allowable level, the simulation could have been rerun with an accuracy level of 1. If convergence had not been reached within 20 cycles, a value of 40, for example, might have been entered provided that the costs for added computer time were acceptable.

In Table 5, the actual computer printout provided for the input data and instructions of Figure 2 have been arranged in a convenient tabulation showing each of four separate printout sheets. Printout No. 1 shows the actual summarized input data as entered into the program so that the user can check the data for errors or omissions. Printout No. 2 instructs the user via the statement "There are no errors in the input data" that the modeling program will be executed as requested. Printout No. 3 provides a listing of those parameters whose values were computed or corrected by the program such as a_c and K_2. Again, inspection of these data by the model user allows him to determine the reasonableness of the indicated values. Finally, the AVERAGE data shown in Printout No. 4 indicate that both the pressure drop and penetration expectations for the filter system (< 1750 N/m^2 and 0.5 percent) should be realized. In addition, Printout No. 4 also indicates that 10 cycles rather than the 20 requested on the data input form, were sufficient to define steady state operating conditions.

TABLE 5. SAMPLES OF TABULAR PRINTOUT FOR EXAMPLE OF MODEL APPLICATION

PRINTOUT NO. 1

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SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

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AN ELECTRIC UTILITY / PLANT B BAGHOUSE


BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS              30
     COMPARTMENT CLEANING TIME            1.0          MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                 30.0          MINUTES
     CONTINUOUSLY CLEANED SYSTEM
     REVERSE FLOW VELOCITY             1.3725          M/MIN



OPERATING DATA
     AVERAGE FACE VELOCITY             0.9150          M/MIN
     GAS TEMPERATURE                   177.            DEGREES CENTIGRADE
     INLET DUST CONCENTRATION          11.45           G/M3
          MEASURED AT                   25.            DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2            1.70           N-MIN/G-M
          MEASURED AT                  260.            DEGREES CENTIGRADE
                                       0.6100          M/MIN
                        MMD1          10.0             MICRONS        -STANDARD DEVIATION 3.00
          CORRECTED TO  MMD2           7.0             MICRONS        -STANDARD DEVIATION 2.50

     EFFECTIVE RESIDUAL DRAG, SE       520.            N-MIN/M3
          MEASURED AT                  260.            DEGREES CENTIGRADE
     RESIDUAL LOADING, WR               73.2           G/M2


SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED      20
     ACCURACY LEVEL                    0
     TYPE OF RESULTS REQUESTED         AVERAGE /
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PRINTOUT NO. 2

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 DIAGNOSTIC MESSAGES


 THERE ARE NO ERRORS IN THE INPUT DATA
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(continued)

TABLE 5 (continued)

PRINTOUT NO. 3

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	7.58	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	2.14	N-MIN/G-M
EFFECTIVE DRAG, SE	620.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.27	
TIME INCREMENT	0.25	MINUTES
SYSTEM CONSTANT **	0.0	G/M2

PRINTOUT NO. 4

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RESULTS OF BAGHOUSE ANALYSIS

****

AN ELECTRIC UTILITY / PLANT B BAGHOUSE

FOR 30.00 MINUTES OPERATION, CYCLE NUMBER 8			
	AVERAGE PENETRATION=	3.33E-03	
	AVERAGE PRESSURE DROP=	1558.78	N/M2
	AVERAGE SYSTEM FLOW=	0.9607	M/MIN
	MAXIMUM PENETRATION=	4.75E-03	
	MAXIMUM PRESSURE DROP=	1576.12	N/M2
FOR 30.00 MINUTES OPERATION, CYCLE NUMBER 9			
	AVERAGE PENETRATION=	3.33E-03	
	AVERAGE PRESSURE DROP=	1558.04	N/M2
	AVERAGE SYSTEM FLOW=	0.9607	M/MIN
	MAXIMUM PENETRATION=	4.74E-03	
	MAXIMUM PRESSURE DROP=	1574.95	N/M2
FOR 30.00 MINUTES OPERATION, CYCLE NUMBER 10			
	AVERAGE PENETRATION=	3.33E-03	
	AVERAGE PRESSURE DROP=	1557.74	N/M2
	AVERAGE SYSTEM FLOW=	0.9607	M/MIN
	MAXIMUM PENETRATION=	4.74E-03	
	MAXIMUM PRESSURE DROP=	1574.50	N/M2

REFERENCES

1. Billings, C. E., and J. E. Wilder. Handbook of Fabric Filter Technology, Volume I, Fabric Filter Systems Study, 1970. U.S. Environmental Protection Agency, Control Systems Laboratory, Research Triangle Park, North Carolina. EPA-APTD 0690 (NTIS No. PB-200-648). December 1970.

2. Dennis, R., and J. E. Wilder. Fabric Filter Cleaning Studies. U.S. Environmental Protection Agency, Control Systems Laboratory, Reseach Triangle Park, North Carolina. EPA-650/2-75-009 (NTIS No. PB-240-372/3G1). January 1975.

3. Hall, R. R., and R. Dennis. Mobile Fabric Filter System. Environmental Protection Agency, Control Systems Laboratory, Research Triangle Park, North Carolina. Report No. EPA-650/2-75-059 (NTIS No. PB-246-287/AS). July 1975.

4. Dennis, R., et al. Filtration Model for Coal Fly Ash with Glass Fabrics. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. EPA-600/7-77-084. August 1977.

5. Dennis, R., R. W. Cass, and R. R. Hall. Dust Dislodgement From Woven Fabrics Versus Filter Performance. J Air Pollu Control Assoc. 48 No. 1, 47. 1978.

6. Dennis, R., and N. F. Surprenant. Particulate Control Highlights: Research on Fabric Filtration Technology. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. EPA-600/8-78-005d. June 1978.